



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Processing speed and visuospatial executive function predict visual working memory ability in older adults

Citation for published version:

Brown, LA, Brockmole, JR, Gow, AJ & Deary, IJ 2012, 'Processing speed and visuospatial executive function predict visual working memory ability in older adults', *Experimental Aging Research*, vol. 38, no. 1, pp. 1-19. <https://doi.org/10.1080/0361073X.2012.636722>

Digital Object Identifier (DOI):

[10.1080/0361073X.2012.636722](https://doi.org/10.1080/0361073X.2012.636722)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Publisher's PDF, also known as Version of record

Published In:

Experimental Aging Research

Publisher Rights Statement:

©Brown, L. A., Brockmole, J. R., Gow, A. J., & Deary, I. J. (2012). Processing speed and visuospatial executive function predict visual working memory ability in older adults. *Aging clinical and experimental research*, 38(1), 1-19doi: 10.1080/0361073X.2012.636722

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



This article was downloaded by: [University of Edinburgh]

On: 17 January 2014, At: 08:36

Publisher: Routledge

Informa Ltd Registered in England and Wales Registered Number: 1072954

Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Experimental Aging Research: An International Journal Devoted to the Scientific Study of the Aging Process

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/uear20>

Processing Speed and Visuospatial Executive Function Predict Visual Working Memory Ability in Older Adults

Louise A. Brown ^a, James R. Brockmole ^b, Alan J. Gow ^c & Ian J. Deary ^c

^a Department of Psychology, The University of Edinburgh, Edinburgh, UK

^b Department of Psychology, University of Notre Dame, Notre Dame, Indiana, USA

^c Department of Psychology and Centre for Cognitive Ageing and Cognitive Epidemiology, The University of Edinburgh, Edinburgh, UK

Published online: 06 Jan 2012.

To cite this article: Louise A. Brown, James R. Brockmole, Alan J. Gow & Ian J. Deary (2012) Processing Speed and Visuospatial Executive Function Predict Visual Working Memory Ability in Older Adults, *Experimental Aging Research: An International Journal Devoted to the Scientific Study of the Aging Process*, 38:1, 1-19, DOI: [10.1080/0361073X.2012.636722](https://doi.org/10.1080/0361073X.2012.636722)

To link to this article: <http://dx.doi.org/10.1080/0361073X.2012.636722>

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at <http://www.tandfonline.com/page/terms-and-conditions>

PROCESSING SPEED AND VISUOSPATIAL EXECUTIVE FUNCTION PREDICT VISUAL WORKING MEMORY ABILITY IN OLDER ADULTS

Louise A. Brown

Department of Psychology, The University of Edinburgh, Edinburgh, UK

James R. Brockmole

Department of Psychology, University of Notre Dame, Notre Dame,
Indiana, USA

Alan J. Gow

Ian J. Deary

Department of Psychology and Centre for Cognitive Ageing and Cognitive
Epidemiology, The University of Edinburgh, Edinburgh, UK

Background/Study Context: Visual working memory (VWM) has been shown to be particularly age sensitive. Determining which measures share variance with this cognitive ability in older adults may help to elucidate the key factors underlying the effects of aging.

Received 12 September 2010; accepted 27 May 2011.

This research was funded by European Research Council grant 201312 awarded to J.R.B., who is also an Honorary Fellow at The University of Edinburgh. The authors thank Paula Davies and the Lothian Birth Cohort 1936 participants for their assistance with the project. I.J.D. and A.J.G. are members of The University of Edinburgh Centre for Cognitive Ageing and Cognitive Epidemiology, part of the cross council Lifelong Health and Wellbeing Initiative (G0700704/84698). Funding from the BBSRC, EPSRC, ESRC, and MRC is gratefully acknowledged.

Address correspondence to Dr. Louise A. Brown, Division of Psychology, School of Social Sciences, Nottingham Trent University, Burton Street, Nottingham NG1 4BU, UK. E-mail: louise.brown@ntu.ac.uk

Methods: Predictors of VWM (measured by a modified Visual Patterns Test) were investigated in a subsample (N = 44, mean age = 73) of older adults from the Lothian Birth Cohort 1936 (LBC1936; Deary et al., 2007, BMC Geriatrics, 7, 28). Childhood intelligence (Moray House Test) and contemporaneous measures of processing speed (four-choice reaction time), executive function (verbal fluency; block design), and spatial working memory (backward spatial span), were assessed as potential predictors.

Results: All contemporaneous measures except verbal fluency were significantly associated with VWM, and processing speed had the largest effect size ($r = -.53$, $p < .001$). In linear regression analysis, even after adjusting for childhood intelligence, processing speed and the executive measure associated with visuospatial organization accounted for 35% of the variance in VWM.

Conclusion: Processing speed may affect VWM performance in older adults via speed of encoding and/or rate of rehearsal, while executive resources specifically associated with visuospatial material are also important.

Working memory is the limited-capacity cognitive system that allows for the simultaneous retention and manipulation of information. As individuals age, however, working memory performance declines (Bopp & Verhaeghen, 2005; Park et al., 2002), which can lead to difficulty performing a multitude of everyday activities. As such, working memory tasks have become an important component of cognitive batteries designed to investigate and characterize age-related changes in mental ability. Unfortunately, the majority of this work has focused on either the verbal or domain-general components of working memory, whereas much less research has specifically focused on the visuospatial component that supports memory for objects, faces, and scenes. The evidence that does exist in this area suggests that visuospatial working memory may in fact be more age sensitive than verbal working memory (Jenkins, Myerson, Joerding, & Hale, 2000; Johnson, Logie, & Brockmole, 2010; Leonards, Ibanez, & Giannakopoulos, 2002; Myerson, Hale, Rhee, & Jenkins, 1999; but see Kemps & Newson, 2006; Park et al., 2002). In particular, working memory for abstract visual information (Smith, Park, Cherry, & Berkovsky, 1990), such as black and white matrix (chequered) patterns (Beigneux, Plaie, & Isingrini, 2007; Brown, McConnell, & Forbes, 2011; Bruyer & Scailquin, 1999; Logie & Maylor, 2009), is especially age sensitive. The purpose of the present study was to determine the degree to which a variety of cognitive measures share variance with visual working memory in an effort to elucidate, within

the working memory architecture, the factors that contribute to these marked age-related changes in visual working memory ability.

A standardized measure of visual working memory is the Visual Patterns Test (VPT; Della Sala, Gray, Baddeley, & Wilson, 1997) during which participants are shown black and white chequered patterns of increasing complexity and are asked to recall each pattern in turn, either immediately or following a delay period (typically 10 s; Della Sala, Gray, Baddeley, Allamano, & Wilson, 1999; see Figure 1). Using a modified version of this task, which more tightly restricts verbal encoding (Brown, Forbes, & McConnell, 2006), Brown and colleagues (2011) demonstrated marked decrements ($\eta_p^2 = .29-.35$, independent of years of education) in the performance of older adults relative to young adults. With the aim of determining what accounts for this decrement, we examined the degree to which three important cognitive abilities may be related to visual working memory decline: processing speed (as measured by four-choice reaction time), executive function (as measured by verbal fluency and block design), and spatial working memory (as measured by backward spatial span). In addition, an important correlate of adult cognitive functioning, childhood intelligence, was included in our assessment, because this variable is an indicator of the preexisting individual differences in general cognitive ability. Visual working memory was measured by the modified VPT, in a sample of older adults (aged 73) from the Lothian Birth Cohort 1936 (LBC1936; see Deary et al., 2007), who are well characterized in terms of current cognitive function as well as childhood intelligence. The rationale for selecting the domains under investigation is described below.

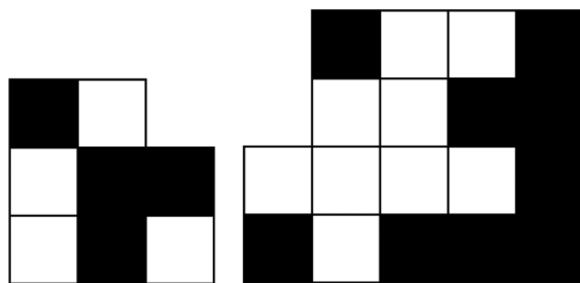


Figure 1. Sample stimuli from the modified Visual Patterns Test (levels 4 and 9).

Childhood Intelligence

Intelligence has been shown to remain relatively stable between childhood and older adulthood, and to be associated with achievement and health outcomes throughout the life span (see Deary, Whalley, & Starr, 2009, and Deary, Penke, & Johnson, 2010, for reviews). This suggests that preexisting differences in cognitive ability can account for some of the variance in ability measured later in the life span, thus limiting the extent of the variance that is due to cognitive aging per se. One of the strengths of LBC1936, therefore, is the availability of a valid measure of intelligence in childhood that allows the variance in initial cognitive ability (measured early in the life span) to be partitioned from variance in contemporaneous cognitive measures (i.e., those taken within older adulthood).

At age 11, as part of the Scottish Mental Survey 1947 (SMS1947), each member of LBC1936 was administered a version of the Moray House Test No. 12 (MHT), a valid measure of intelligence. Subsequently, at around age 70, members were administered the MHT again, along with a large battery of other cognitive tests designed to tap a variety of specific functions (see Deary et al., 2007). The correlation between the two administrations of the same test, almost 60 years apart, was .692 (Deary, Johnson, & Starr, 2010). This means that the data relating to numerous cognitive measures were available for use in the present study, including intelligence in childhood and in older adulthood. In a study investigating the stability of psychometric intelligence across the life span in a cohort resulting from the Scottish Mental Survey 1932 (the Aberdeen Birth Cohort 1921; ABC1921), Deary, Whalley, Lemmon, Crawford, and Starr (2000) showed that the greatest predictor of MHT performance in a sample of older adults aged 79 was childhood performance, accounting for about half of the variance. Deary, Whiteman, Starr, Whalley, and Fox (2004) later confirmed this level of shared variance within the Lothian Birth Cohort 1921 (LBC1921), a much larger cohort than ABC1921. Furthermore, because individual differences tend to be stable across cognitive domains (Deary, Penke, et al., 2010) it is important to control for childhood intelligence when assessing the influence of other variables, such as nutritional status (Deary et al., 2004) or processing speed (Deary, Johnson, et al., 2010), on cognitive ability in older adulthood. In addition to childhood intelligence, a contemporaneous measure of intelligence, also derived using the MHT, was also available for each participant, and this allowed for the investigation of the stability of intelligence across the life span (see Deary, Johnson, et al., 2010; Gow et al., 2011).

Processing Speed

Salthouse (1991) proposed that age-related changes in “fluid” cognition, such as memory, reasoning, and spatial abilities, are due to a decrease in the speed with which cognitive operations may be carried out (see Salthouse, 1996, for a review). Two mechanisms may be responsible for this relationship. The limited time mechanism, in which slowed operations (e.g., associations, elaborations, and rehearsals) cannot be completed successfully in the available time, may exert a greater effect in more complex tasks, which are dependent upon the outcome of a number of simpler operations. The simultaneity mechanism, in which slower processing results in a reduction in the simultaneously available information required by dynamic systems including working memory, affects the performance of higher-order functions such as abstraction, elaboration, and integration. Supporting evidence includes moderate to high proportions of shared variance between measures of processing speed and a range of cognitive tasks, including memory, and the attenuation of the effects of age when processing speed is controlled (e.g., Finkel, Reynolds, McArdle, & Pedersen, 2007; Salthouse, 1992, 1994b; Vaughan & Hartman, 2010; Verhaeghen & Salthouse, 1997).

Importantly, Deary, Johnson, and colleague (2010) found that, whereas processing speed was contemporaneously associated with general cognitive ability in older adulthood, these relationships were attenuated when childhood mental ability was taken into account. The authors did show, however, that simpler measures, including four-choice reaction time, exhibit a smaller relationship with childhood ability than more complex measures, such as the Digit Symbol task from the Wechsler battery, and could therefore serve as biomarkers of cognitive aging. Four-choice reaction time was therefore included as the measure of processing speed in the current study.

Central Executive Function

Although theoretical perspectives on the structure, components, and independence of working memory vary (e.g., see Baddeley, 2000; Baddeley & Hitch, 1974; Cowan, 2001; Kane & Engle, 2002; Logie, 1995, 2003; Lovett, Reder, & Lebiere, 1999), there is general agreement that the system depends crucially upon the operation of capacity-limited attentional processes (the *central executive*; Baddeley, 2000). A number of authors have critically implicated reduced frontal lobe/attentional resources (to which we will refer as central executive function) in the effects of cognitive aging (e.g., Craik

& Byrd, 1982; Dempster, 1992; West, 1996; see Braver & West, 2008, for a recent review). This account of cognitive aging is supported by neuroimaging evidence such as demonstrations of greater age-related decline in white matter integrity in anterior brain regions (Brickman et al., 2006; Buckner, 2004; Head et al., 2004), underrecruitment of frontal brain regions in older adults during tasks involving intentional memory encoding (Logan, Sanders, Snyder, Morris, & Buckner, 2002), and reduced attention-related frontal activity accompanied by increased distractor-related activity in older adults (Chao & Knight, 1997). At the behavioral level, MacPherson, Phillips, and Della Sala (2002) provided evidence that specifically the dorsolateral prefrontal cortex, the area believed to be responsible for executive function, undergoes age-related decline.

Verbal fluency has been associated with central executive functioning (Lezak, Howieson, & Loring, 2004; Stuss et al., 1998) and is a frequently used measure of this ability in healthy and patient populations (Baddeley, Emslie, Kolodny, & Duncan, 1998; Fisk & Sharp, 2004; Salthouse, Atkinson, & Berish, 2003). We used this measure to tap general central executive function. However, block design is also frequently associated with central executive/frontal lobe function (Lezak et al., 2004; Wallesch, Curio, Galazky, Jost, & Synowitz, 2001) and assesses strategy and planning skills in the specific context of a visuospatial construction task. We therefore employed this as a second measure of central executive function. It was possible for this to share more variance with visual working memory performance than the verbal fluency measure, due to block design's relation to specifically visuospatial planning/organization.

Spatial Working Memory

From the multicomponent perspective on working memory, modality-specific subsystems are believed to control visuospatial and verbal storage and processing. Following the further specification of the verbal subsystem (phonological loop) as comprising separable storage and rehearsal processes (see Baddeley, 2000), Logie (1995, 2003) suggested that the visuospatial subsystem is also comprised of separable components. A visual storage component and a more dynamic spatial rehearsal component were both proposed to exist. Whereas the visual component is sensitive to decay and interference, the spatial rehearsal mechanism actively refreshes the contents of the store and helps to retain spatiosequential information. Supporting evidence includes dissociations in the dual-task interference effects during visual and spatial working memory tasks

(e.g., Della Sala et al., 1999; Klauer & Zhao, 2004; Quinn & McConnell, 1996). For example, Della Sala and colleagues used the VPT to show that visual interference disrupts visual working memory to a greater extent than spatial working memory, whereas the opposite was true for a spatial interference task.

Including a measure of spatial working memory in the current study (the Corsi-type backward spatial span task from the Wechsler Memory Scale—III UK, WMS-III UK; Wechsler, 1998b) allowed for the investigation of the extent to which these two processes shared variance. Based upon the above evidence, however, although the two tasks have the short-term retention of visuospatial information in common, it was expected that the separability of the two processes would limit the predictive power of spatial working memory.

METHODS

Participants

Members of LBC1936 were administered the MHT at age 11. Subsequently, at approximately age 70, the cohort members were administered a battery of tests that has been described in detail previously (Deary et al., 2007). Around 3 years later, a sample of the cohort's earliest recruited members was recruited for this study ($N = 44$; note that age-11 IQ was unavailable for 1 participant). The mean age of this sample was 10.93 years ($SD = 0.27$) when completing the MHT in childhood, and 68.34 ($SD = 0.35$) when followed up in older adulthood for LBC1936. The mean age when carrying out the VPT was 72.76 ($SD = 0.32$). There were 19 males and 25 females, and the mean number of years of education was 13.60 ($SD = 3.32$). All participants were cognitively healthy, as determined by the Mini-Mental State Examination (MMSE), which screened for dementia (Folstein, Folstein, & McHugh, 1975). The mean MMSE score was 29.52 ($SD = 0.82$, range = 27–30). All participants reported normal or corrected-to-normal visual acuity, which was confirmed by near-perfect performance on practice trials.

Measures

Visual Working Memory

Participants were administered a modified version of the VPT (see Brown et al., 2006; Della Sala et al., 1997). This task involves presenting participants with a series of black and white chequered patterns

that increase in size and therefore complexity (see Figure 1). Participants were required to recall each pattern in turn by placing an “X” in the cells of blank paper templates that they remembered to be black. Each trial consisted of a fixation cross (2 s), the presentation of the pattern (3 s), a delay (maintenance) period (10 s), and finally the word *recall* displayed on the computer screen, which prompted participants to respond. There were three practice trials followed by three trials at each of the levels of complexity 4 through 9 (with level of complexity referring to the number of black cells to be recalled). All participants were administered the same number of trials (18). The outcome measure used was the total number of correct patterns recalled.¹

Intelligence

The Moray House Test No. 12 (MHT) was administered as part of the Scottish Mental Survey 1947 and provides the measure of intelligence in childhood (age 11) and in older adulthood (age 68). In both childhood and older adulthood the raw MHT scores were corrected for age in days at the time of testing and converted into intelligence quotient-type (IQ) scores with mean = 100, *SD* = 15.

Processing Speed

Four-choice reaction time measured information processing speed using a response box (see Deary, Der, & Ford, 2001, for details). Briefly, the box features five keys arranged in an arc and labeled 1, 2, 0, 3, 4, and the participants rest the second and third fingers of the left and right hand on the “1,” “2,” “3,” and “4,” keys, respectively. The task is to press the correct button as quickly as possible in response to one of these four digits appearing on a liquid crystal display (LCD) at the top of the box. There were 8 practice trials and 40 test trials. Each number appeared 10 times in a randomized order. There was an interval of between 1 and 3 s between the participant’s response and the onset of the next stimulus. Resulting reaction time scores were taken only from the correct trials.

Central Executive Function

Verbal fluency provided one measure of central executive function (Lezak et al., 2004) and required participants to name as many words as possible beginning with the letters C, F, and L, with 1 min provided for each letter. Proper names were not allowed and no additional score was given for repeated words. The resulting measure

¹The mean percentage of cells correctly recalled was highly correlated with the mean number of patterns correctly recalled ($r = .91$), and both measures yield the same results.

was the total number of correct words. The Block Design subtest of the Wechsler Adult Intelligence Scale—III UK (WAIS-III UK; Wechsler, 1998a) was included as a second measure of executive function involving visuospatial organization, and required participants to plan and develop strategies for constructing designs from their constituent parts (individual blocks).

Spatial Working Memory

The Backward Spatial Span subtest of the WMS-III UK (Wechsler, 1998b) provided a measure of spatial working memory performance. In this task the experimenter tapped out a sequence upon a selection of 10 cubes irregularly spaced across a rectangular board and participants were required to tap out the sequence in the opposite order. Sequences increased from two to nine blocks in length, with two sequences at each level, and the test terminated when the participant failed to recall correctly both sequences from a given level.

RESULTS

Descriptive statistics and Pearson correlations between all variables are provided in Table 1.² Age-11 and age-68 MHT IQ scores correlated highly ($r = .71, p < .001$). In our modest sample, age-11 IQ did not correlate significantly with visual working memory ($r = .26, p = .09$), but contemporaneous (age-68) IQ did so ($r = .43, p < .01$). Interestingly, age-11 IQ correlated significantly with all variables except visual working memory and spatial working memory ($r = .14, p = ns$).

With the exception of verbal fluency and age-11 IQ, all measures correlated significantly with visual working memory, in the direction that better scores were related to better visual working memory performance. The largest correlation was with processing speed ($r = -.53, p < .001$), closely followed by block design ($r = .50, p < .01$) and spatial working memory ($r = .48, p < .01$). With verbal fluency failing to correlate significantly with visual working memory,

²Our results suggest a strong positive manifold among the scores derived from the administered tests; indeed, this has been found in every cognitive data set since Spearman first described it in 1904 (see Carroll, 1993). That said, we used tasks to represent key theoretical processes in cognitive aging and asked if these can account for performance on the visual working memory task. We therefore accepted, a priori, the role of processing speed and executive function as possible drivers of the cognitive aging process, which legitimized their being used as the predictor variables. Thus, despite the positive manifold, not all of the positively correlated variables has equal explanatory status.

Table 1. Means (with standard deviations) and Pearson correlations between each variable

	1	2	3	4	5	6	7	<i>M (SD)</i>
1. Age-11 IQ	—							105.21 (14.77)
2. Age-68 IQ	.71***	—						102.08 (12.42)
3. Processing speed (four-choice reaction time)	-.45**	-.51***	—					0.623 (0.081)
4. Central executive function (verbal fluency)	.44**	.47**	-.28	—				44.84 (13.16)
5. Visuospatial organization (block design)	.44**	.58***	-.37*	.30*	—			38.73 (10.77)
6. Spatial working memory (backward spatial span)	.14	.23	-.42**	.42**	.40**	—		7.95 (1.52)
7. Visual working memory (modified Visual Patterns Test)	.26	.43**	-.53***	.09	.50**	.48**	—	8.77 (3.30)

Note. All correlations based upon $N=44$, except those involving age-11 IQ for which $N=43$.

* $p < .05$; ** $p < .01$; *** $p < .001$.

it is notable that this variable did not correlate significantly with processing speed, the variable with which visual working memory was most highly correlated. In fact, the highest correlation coefficients involving verbal fluency were with the IQ measures, taken both at age 11 ($r = .44, p < .01$) and at age 68 ($r = .47, p < .01$). On the other hand, block design correlated with all variables, but the strongest relations were with age-68 IQ ($r = .58, p < .001$) and visual working memory ($r = .50, p < .01$). Finally, spatial working memory correlated with processing speed ($r = -.42, p < .01$), verbal fluency ($r = .42, p < .01$), and block design ($r = .40, p < .01$) at similar levels, but not with the two IQ measures.

Linear Regression Modeling

Stepwise linear regression analyses were carried out to discover the amount of shared variance existing between visual working memory and the potential predictors. In the first of two models, all variables including age-68 IQ and sex were included. The second model was hierarchical, with age-11 IQ entered in the first block, in order to determine whether or not childhood ability attenuates the variance in visual working memory predicted by the significant predictors from Model 1, which were entered in the second block using the stepwise method. The models are displayed in Table 2.

Model 1 was significant, $F(2, 43) = 12.83, p < .001$, and predicted 36% of the variance in visual working memory performance ($R = .62$, adjusted $R^2 = .36, SE = 2.65$). Processing speed ($\beta = -.40, p < .01$) and block design ($\beta = .35, p = .01$) served as significant

Table 2. Linear regression models predicting visual working memory performance in older adulthood

	B	Standard error B	β	$t(p)$
Model 1				
Processing speed	-16.13	5.38	-.40	-3.00 (.005)
Visuospatial organization	.11	.04	.35	2.66 (.011)
Model 2a				
Age-11 IQ	.06	.03	.26	1.72 (.092)
Model 2b				
Age-11 IQ	-.02	.03	-.10	-.71 (.484)
Processing speed	-17.90	5.80	-.44	-3.09 (.004)
Visuospatial organization	.11	.04	.37	2.61 (.013)

Note. In Model 2, age-11 IQ was entered in Block 1, whereas processing speed and visuospatial organization were entered stepwise in Block 2. Model 2b is the final model.

predictors in the model, with processing speed predicting 16%, and block design predicting 12%, of the variance. Within this sample and combination of predictors, all other variables were nonsignificant and so were excluded from the second model. Including age-11 IQ in the second model did not alter the pattern of results, $F(3, 42) = 8.46$, $p < .001$. This model predicted 35% of the variance ($R = .63$, adjusted $R^2 = .35$, $SE = 2.67$), with processing speed ($\beta = -.44$, $p < .01$) predicting 20%, and block design ($\beta = .37$, $p = .01$) predicting 14%, of the variance in visual working memory performance. Therefore, childhood ability did not serve as a significant predictor ($\beta = -.10$, $p = ns$).

DISCUSSION

This study was aimed at determining predictors of visual working memory performance, as measured by a visual matrix task (modified VPT; Brown et al., 2006; Della Sala et al., 1997, 1999), in a sample of healthy older adults recruited from the Lothian Birth Cohort 1936 (LBC1936; Deary et al., 2007). Visual working memory was related to processing speed, block design, spatial working memory, and older age IQ, but neither to verbal fluency nor childhood IQ (measured at age 11). As the only variables retained in a regression analysis, processing speed and block design (the visuo-spatial executive measure) were the significant predictors of visual working memory performance. An important aim of the present study, however, was to establish whether any predictive value would remain after previous mental ability (age-11 IQ) was adjusted for (Deary et al., 2000, 2004; Deary, Johnson, et al., 2010; Deary et al., 2009). After age-11 IQ was included, the pattern of results remained the same, with processing speed predicting 20%, and block design predicting 14%, of the variance, suggesting that, with this sample and sample size, visual working memory performance in older adulthood is not related to initial general cognitive ability. Rather, visual working memory ability appears to be related to changes that have occurred with the aging process, and most likely reflects the fluid nature of the task. It may have been possible for the measure of childhood intelligence to be unreliable; however, there is strong stability in intelligence across the life span in LBC1936, and this was one of the advantages of drawing upon this sample (Deary, Johnson, et al., 2010; Gow et al., 2011). Furthermore, a strong positive correlation is also evident in this subsample.

Consideration of the remaining key variables of processing speed and central executive function offers insight regarding the processes affecting visual working memory performance in older age, and age-related cognitive decline more generally. The finding that the verbal fluency central executive measure was neither correlated with, nor predictive of, visual working memory performance suggests that decline in visual working memory is not simply due to general central executive dysfunction, but may be due to more widespread deterioration (Band, Ridderinkhof, & Segalowitz, 2002; Greenwood, 2000; Tisserand & Jolles, 2003). On the other hand, central executive resources specifically related to the organization of visuospatial material were shown to be important. As indicated by the shared variance with block design, the deployment of central executive resources within the context of a visuospatial task appears to be particularly important.

The finding that processing speed exhibited the greatest correlation with visual working memory performance, as well as the greatest predictive value, suggests that speed of encoding (the ability to create a stable representation; Salthouse, 1994a) and/or rate of rehearsal are possible candidates for the source of the marked age-related deficit in visual working memory performance. Indeed, elaborations and rehearsals are two possible operations referred to by Salthouse (1996) that could be affected by speed of processing. Within the visual working memory task, it is clear that slower elaboration during pattern encoding time, as well as slower rehearsal speed during the delay period, could each contribute to poorer recall. Similarly, the simultaneity mechanism offers a conceivable explanation regarding the role of processing speed. Poorer recall could be observed when the result of previous operations is no longer available by the time subsequent operations are completed (i.e., rehearsing individual component parts of the stimuli in turn). Participants with slower processing speed may therefore find themselves able to recall only part of a pattern, or none of the pattern at all.

Inspecting the pattern of correlations with the spatial working memory measure may offer further insight, as this task was related to processing speed and both central executive measures. It is possible that, unlike the visual working memory task, spatial working memory was more related to central executive function due to the requirement of participants to manipulate the information (i.e., reverse sequence order) before providing the response. However, visuospatial encoding, representation, maintenance, and elaboration are likely to be represented by processing speed and visuospatial organization (block design), the two variables that were also related to, and predictive of, visual working memory. Although visual and spatial working

memory were moderately correlated, and each appear to have processing speed and visuospatial organization in common, spatial working memory did not predict visual working memory performance. This finding supports the theory that visual and spatial working memory are related but separable processes (Della Sala et al., 1999; Logie, 1995, 2003).

At the biological level, the processing speed deficit could be related to a reduction in white matter integrity. Deary et al. (2006; see also Bucur et al., 2008; Kennedy & Raz, 2009; Madden et al., 2008) showed that white matter integrity, believed to be crucial for connectivity between the distributed cortical regions that underlie cognition, is related to efficiency of information processing and cognitive ability in older age. Specifically, white matter integrity was related to reaction time measures of information processing as used in the current study. Furthermore, Waiter et al. (2008) provided functional magnetic resonance imaging (fMRI) evidence that successful cognitive aging may be related to the preservation of neural networks subserving such simple information processing.

It is important to highlight the potential limitations of the current study. First, the sample size is relatively small, and it is therefore possible that lack of power did not allow for the detection of small effects, particularly with respect to the correlation between childhood IQ and visual working memory, which exhibited a trend toward significance. Despite this limitation, however, clear results have been found relating to the predictive value of the variables under investigation. A further limitation relates to the lack of correlation with, and predictive power of, verbal fluency. Although this has been widely used and accepted as a measure of central executive function (e.g., see Lezak et al., 2004; Stuss et al., 1998), Tisserand and Jolles (2003) highlighted that prefrontal decline may have to be considered as separable. That is, verbal fluency may not tap the most age-sensitive function(s) carried out by prefrontal cortex. Furthermore, Phillips (1999) stated that verbal fluency performance must be interpreted with caution, as poorer performance may reflect a number of factors such as general intelligence (see also Salthouse et al., 2003). Nevertheless, central executive function was found to relate to spatial working memory, which involved manipulation of stimuli prior to response. As highlighted above, performance of the visual working memory task may simply not draw upon central executive function to a large enough extent for the shared variance to go beyond central executive processing specifically involved with visuospatial material. Finally, there remains a large proportion of variance in visual working memory performance that is unexplained

in the current study. At the heart of visual working memory performance is short-term maintenance of specifically visual information (i.e., a static visual image). It is likely that this process would have accounted for a significant proportion of the variance, yet no other measures were available to us that would have captured this process.

In summary, neither childhood ability nor verbal fluency predicted visual working memory in the present study, but processing speed was able to predict 20% of the variance, whereas visuospatial organization (block design) predicted 14%. It is suggested that processing speed affects task performance via speed of encoding and/or rate of rehearsal, and that central executive resources specifically related to the use of visuospatial material are important for visual working memory performance in older adults. As suggested by recent research, processing speed may indeed be a biomarker of cognitive aging (Deary, Johnson, et al., 2010).

REFERENCES

- Baddeley, A. D. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences*, 4, 417–423.
- Baddeley, A., Emslie, H., Kolodny, J., & Duncan, J. (1998). Random generation and executive control of working memory. *Quarterly Journal of Experimental Psychology*, 51A, 819–852.
- Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York: Academic Press.
- Band, G. P. H., Ridderinkhof, K. R., & Segalowitz, S. (2002). Explaining neurocognitive aging: Is one factor enough? *Brain and Cognition*, 49, 259–267.
- Beigneux, K., Plaie, T., & Isingrini, M. (2007). Aging effects on visual and spatial components of working memory. *International Journal of Aging & Human Development*, 65, 301–314.
- Bopp, K. L., & Verhaeghen, P. (2005). Aging and verbal memory span: A meta-analysis. *Journal of Gerontology: Psychological Sciences*, 60, 223–233.
- Braver, T. S., & West, R. L. (2008). Working memory, executive control, and aging. In F. I. M. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition* (3rd ed., pp. 311–372). New York: Psychology Press.
- Brickman, A. M., Zimmerman, M. E., Paul, R. H., Grieve, S. M., Tate, D. F., Cohen, R. A., et al. (2006). Regional white matter and neuropsychological functioning across the adult lifespan. *Biological Psychiatry*, 60, 444–453.
- Brown, L. A., Forbes, D., & McConnell, J. (2006). Limiting the use of verbal coding in the Visual Patterns Test. *Quarterly Journal of Experimental Psychology*, 59, 1169–1176.
- Brown, L. A., McConnell, J., & Forbes, D. (2011). Interference and aging effects in visual working memory. Submitted.

- Bruyer, R., & Scailquin, J. C. (1999). Assessment of visuo-spatial short-term memory and effect of aging. *European Review of Applied Psychology*, 49, 175–181.
- Buckner, R. L. (2004). Memory and executive function in aging and AD: Multiple factors that cause decline and reserve factors that compensate. *Neuron*, 44, 195–208.
- Bucur, B., Madden, D. J., Spaniol, J., Provenzale, J. M., Cabeza, R., White, L. E., et al. (2008). Age-related slowing of memory retrieval: Contributions of perceptual speed and cerebral white matter integrity. *Neurobiology of Aging*, 29, 1070–1079.
- Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies*. New York: Cambridge University Press.
- Chao, L. L., & Knight, R. T. (1997). Prefrontal deficits in attention and inhibitory control with aging. *Cerebral Cortex*, 7, 63–69.
- Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, 24, 87–185.
- Craik, F. I. M., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. I. M. Craik & S. Trehub (Eds.), *Aging and cognitive processes* (pp. 191–211). New York: Plenum Press.
- Deary, I. J., Bastin, M. E., Pattie, A., Clayden, J. D., Whalley, L. J., Starr, J. M., et al. (2006). White matter integrity and cognition in childhood and old age. *Neurology*, 66, 505–512.
- Deary, I. J., Der, G., & Ford, G. (2001). Reaction times and intelligence differences: A population-based cohort study. *Intelligence*, 29, 389–399.
- Deary, I. J., Gow, A. J., Taylor, M. D., Corley, J., Brett, C., Wilson, V., et al. (2007). The Lothian Birth Cohort 1936: A study to examine influences on cognitive ageing from age 11 to age 70 and beyond. *BMC Geriatrics*, 7, 28.
- Deary, I. J., Johnson, W., & Starr, J. M. (2010). Are processing speed tasks biomarkers of cognitive aging? *Psychology and Aging*, 25, 219–228.
- Deary, I. J., Penke, L., & Johnson, W. (2010). The neuroscience of human intelligence differences. *Nature Reviews: Neuroscience*, 11, 201–211.
- Deary, I. J., Whalley, L. J., & Starr, J. M. (2009). *A lifetime of intelligence: Follow-up studies of the Scottish Mental Surveys of 1932 and 1947*. Washington, DC: American Psychological Association.
- Deary, I. J., Whalley, L. J., Lemmon, H., Crawford, J. R., & Starr, J. M. (2000). The stability of individual differences in mental ability from childhood to old age: Follow-up of the 1932 Scottish Mental Survey. *Intelligence*, 28, 49–55.
- Deary, I. J., Whiteman, M. C., Starr, J. M., Whalley, L. J., & Fox, H. C. (2004). The impact of childhood intelligence on later life: Following up the Scottish Mental Surveys of 1932 and 1947. *Journal of Personality and Social Psychology*, 86, 130–147.
- Della Sala, S., Gray, C., Baddeley, A., Allamano, N., & Wilson, L. (1999). Pattern span: A tool for unwinding visuo-spatial memory. *Neuropsychologia*, 37, 1189–1199.
- Della Sala, S., Gray, C., Baddeley, A., & Wilson, L. (1997). *Visual Patterns Test: A test of short-term visual recall*. Bury St Edmunds, UK: Thames Valley Test Company.

- Dempster, F. N. (1992). The rise and fall of the inhibitory mechanism: Toward unified theory of cognitive development and aging. *Developmental Review*, 12, 45–75.
- Finkel, D., Reynolds, C. A., McArdle, J. J., & Pedersen, N. L. (2007). Age changes in processing speed as a leading indicator of cognitive aging. *Psychology and Aging*, 22, 558–568.
- Fisk, J. E., & Sharp, C. A. (2004). Age-related impairment in executive functioning: Updating, inhibition, shifting, and access. *Journal of Clinical and Experimental Psychology*, 26, 874–890.
- Folstein, M. F., Folstein, S. E., & McHugh, P. R. (1975). Mini-Mental State: A practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, 12, 189–198.
- Gow, A. J., Johnson, W., Pattie, A., Brett, C. E., Roberts, B., Starr, J. M., et al. (2011). Stability and change in intelligence from age 11 to ages 70, 79 and 87: The Lothian Birth Cohorts of 1921 and 1936. *Psychology and Aging*, 26, 232–240.
- Greenwood, P. M. (2000). The frontal aging hypothesis evaluated. *Journal of the International Neuropsychological Society*, 6, 705–726.
- Head, D., Buckner, R. L., Shimony, J. S., Williams, L. E., Akbudak, E., Conturo, T. E., et al. (2004). Differential vulnerability of anterior white matter in nondemented aging with minimal acceleration in dementia of the Alzheimer type: Evidence from diffusion tensor imaging. *Cerebral Cortex*, 14, 410–423.
- Jenkins, L., Myerson, J., Joerding, J. A., & Hale, S. (2000). Converging evidence that visuospatial cognition is more age-sensitive than verbal cognition. *Psychology and Aging*, 15, 157–175.
- Johnson, W., Logie, R. H., & Brockmole, J. R. (2010). Working memory tasks differ in factor structure across age cohorts: Implications for dedifferentiation. *Intelligence*, 38, 513–528.
- Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working memory capacity, executive attention, and general fluid intelligence: An individual differences perspective. *Psychonomic Bulletin & Review*, 9, 637–671.
- Kemps, E., & Newson, R. (2006). Comparison of adult age differences in verbal and visuo-spatial memory: The importance of ‘pure’, parallel and validated measures. *Journal of Clinical and Experimental Neuropsychology*, 28, 341–356.
- Kennedy, K. M., & Raz, N. (2009). Aging white matter and cognition: Differential effects of regional variations in diffusion properties on memory, executive functions, and speed. *Neuropsychologia*, 47, 916–927.
- Klauer, K. C., & Zhao, Z. (2004). Double dissociations in visual and spatial short-term memory. *Journal of Experimental Psychology: General*, 133, 355–381.
- Leonards, U., Ibanez, V., Giannakopoulos, P. (2002). The role of stimulus type in age-related changes of visual working memory. *Experimental Brain Research*, 146, 172–183.
- Lezak, M. D., Howieson, D. B., & Loring, D. W. (2004). *Neuropsychological assessment* (4th ed.). Oxford, UK: Oxford University Press.
- Logan, J. M., Sanders, A. L., Snyder, A. Z., Morris, J. C., & Buckner, R. L. (2002). Under-recruitment and non-selective recruitment: Dissociable neural mechanisms associated with aging. *Neuron*, 33, 827–840.

- Logie, R. H. (1995). *Essays in cognitive psychology: Visuo-spatial working memory*. Hove, UK: Lawrence Erlbaum Associates.
- Logie, R. H. (2003). Spatial and visual working memory: A mental workspace. *The Psychology of Learning and Motivation*, 42, 37–78.
- Logie, R. H., & Maylor, E. A. (2009). An Internet study of prospective memory across adulthood. *Psychology and Aging*, 24, 767–774.
- Lovett, M. C., Reder, L. M., & Lebiere, C. (1999). Modeling working memory in a unified architecture: An ACT-R perspective. In A. Miyake & P. Shah (Eds.), *Models of working memory* (pp. 135–182). New York: Cambridge University Press.
- MacPherson, S. E., Phillips, L. H., & Della Sala, S. (2002). Age, executive function, and social decision making: A dorsolateral prefrontal theory of cognitive aging. *Psychology and Aging*, 17, 598–609.
- Madden, D. J., Spaniol, J., Costello, M. C., Bucur, B., White, L. E., Cabeza, R., et al. (2008). Cerebral white matter integrity mediates adult age differences in cognitive performance. *Journal of Cognitive Neuroscience*, 21, 289–302.
- Myerson, J., Hale, S., Rhee, S. H., & Jenkins, L. (1999). Selective interference with verbal and spatial working memory in young and older adults. *Journal of Gerontology: Psychology Sciences*, 54, 161–164.
- Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging*, 17, 299–320.
- Phillips, L. H. (1999). Age and individual differences in letter fluency. *Developmental Neuropsychology*, 15, 249–267.
- Quinn, J. G., & McConnell, J. (1996). Indications of the functional distinction between the components of visual working memory. *Psychologische Beiträge*, 38, 355–367.
- Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Erlbaum.
- Salthouse, T. A. (1992). Influence of processing speed on adult age differences in working memory. *Acta Psychologica*, 79, 155–170.
- Salthouse, T. A. (1994a). The aging of working memory. *Neuropsychology*, 8, 535–543.
- Salthouse, T. A. (1994b). The nature of the influence of speed on adult age differences in cognition. *Developmental Psychology*, 30, 240–259.
- Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review*, 103, 403–428.
- Salthouse, T. A., Atkinson, T. M., & Berish, D. E. (2003). Executive functioning as a potential mediator of age-related decline in normal adults. *Journal of Experimental Psychology: General*, 132, 566–594.
- Smith, A. D., Park, D. C., Cherry, K., & Berkovsky, K. (1990). Age differences in memory for concrete and abstract pictures. *Journal of Gerontology: Psychological Sciences*, 45, 205–209.
- Stuss, D. T., Alexander, M. P., Hamer, L., Palumbo, C., Dempster, R., Binns, M., et al. (1998). The effects of focal anterior and posterior brain lesions on verbal fluency. *Journal of the International Neuropsychological Society*, 4, 265–278.

- Tisserand, D. J., & Jolles, J. (2003). On the involvement of prefrontal networks in cognitive aging. *Cortex*, 39, 1107–1128.
- Vaughan, L., & Hartman, M. (2010). Aging and visual short-term memory: Effects of object type and information load. *Aging, Neuropsychology, & Cognition*, 17, 35–54.
- Verhaeghen, P., & Salthouse, T. A. (1997). Meta-analyses of age-cognition relations in adulthood: estimates of linear and nonlinear age effects and structural models. *Psychological Bulletin*, 122, 231–249.
- Waiter, G. D., Fox, H. C., Murray, A. D., Starr, J. M., Staff, R. T., Bourne, V. J., et al. (2008). Is retaining the youthful functional anatomy underlying speed of information processing a signature of successful cognitive ageing? An event-related fMRI study of inspection time performance. *Neuroimage*, 41, 581–595.
- Wallesch, C. W., Curio, N., Galazky, I., Jost, S., & Synowitz, H. (2001). The neuropsychology of blunt head injury in the early postacute stage: Effects of focal lesions and diffuse axonal injury. *Journal of Neurotrauma*, 18, 11–20.
- Wechsler, D. (1998a). *WAIS-III UK Administration and scoring manual*. London: Psychological Corporation.
- Wechsler, D. (1998b). *WMS-III Administration and scoring manual*. London: Psychological Corporation.
- West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin*, 120, 272–292.